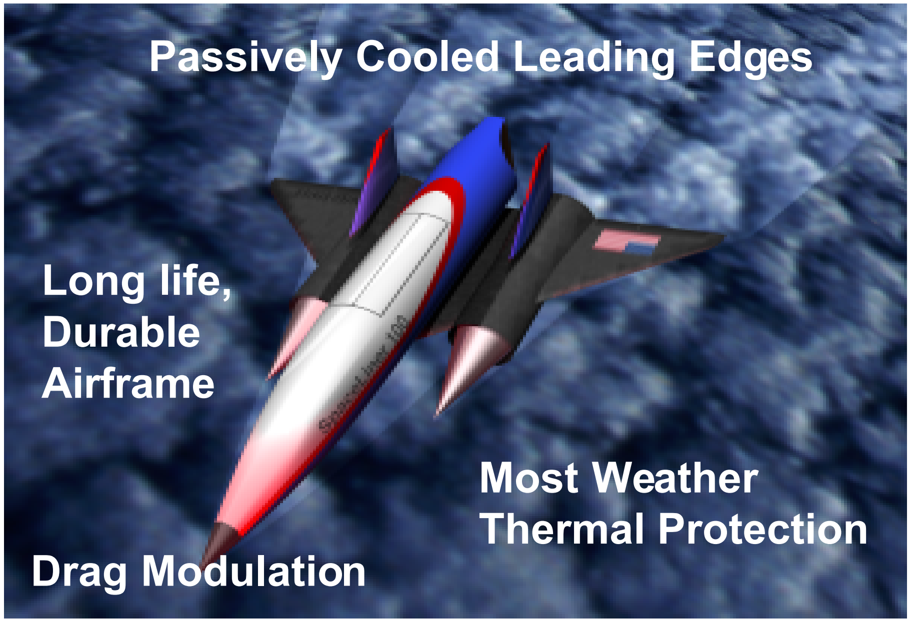
Airframe Technology Project



♦ Project Goal

- Develop and demonstrate airframe technologies that provide a significant reduction in the cost of space transportation systems while dramatically improving the safety and higher operability of those systems.

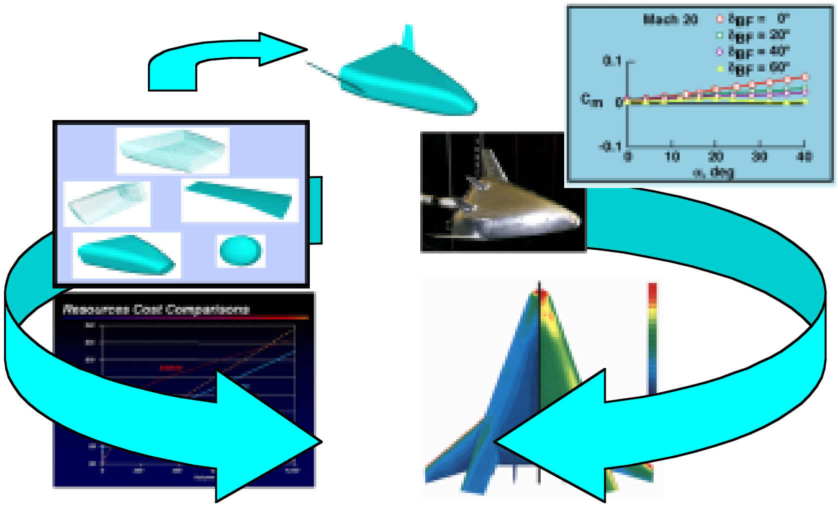
♦ Objective

- Develop airframe tools for ultra-rapid variable-fidelity modeling, analysis, and design
- Develop advanced cryogenic tank, primary structures, hot structures, and thermal protection materials and systems.
  - Includes design and manufacturing tool development, component, subsystems and systems demonstrations as well as life assurance and reusability issues.
- Understand transition and the effects of airframe design on aerodynamic and aerothermodynamic performance.

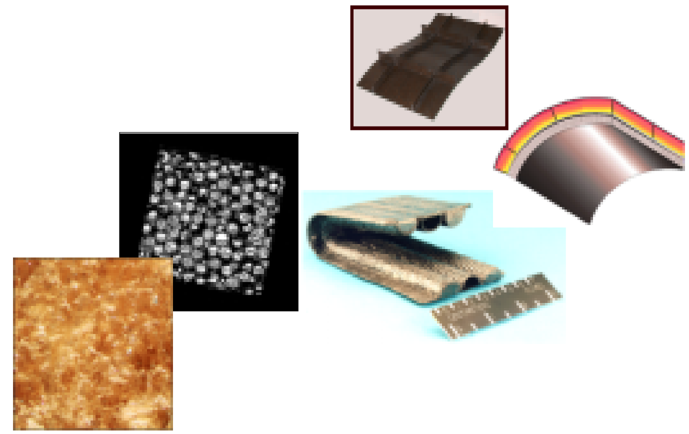
♦ Technical Challenges

- Develop airframe materials and structures required to meet 3rd generation goals.
- Develop airframe design and life cycle prediction tools to meet 3rd generation goals.

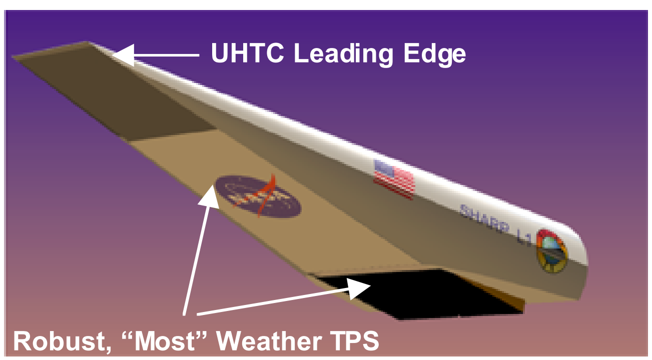
Airframe Technology Elements



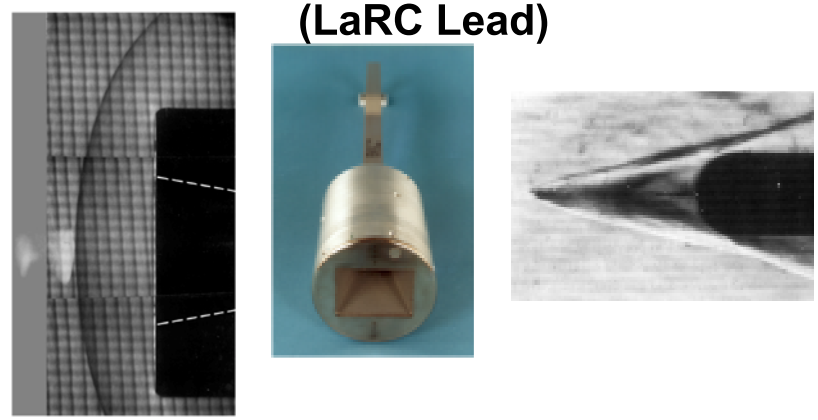
Integrated Airframe Design
(LaRC Lead)



Integrated Thermal Structures and Materials
(LaRC Lead)



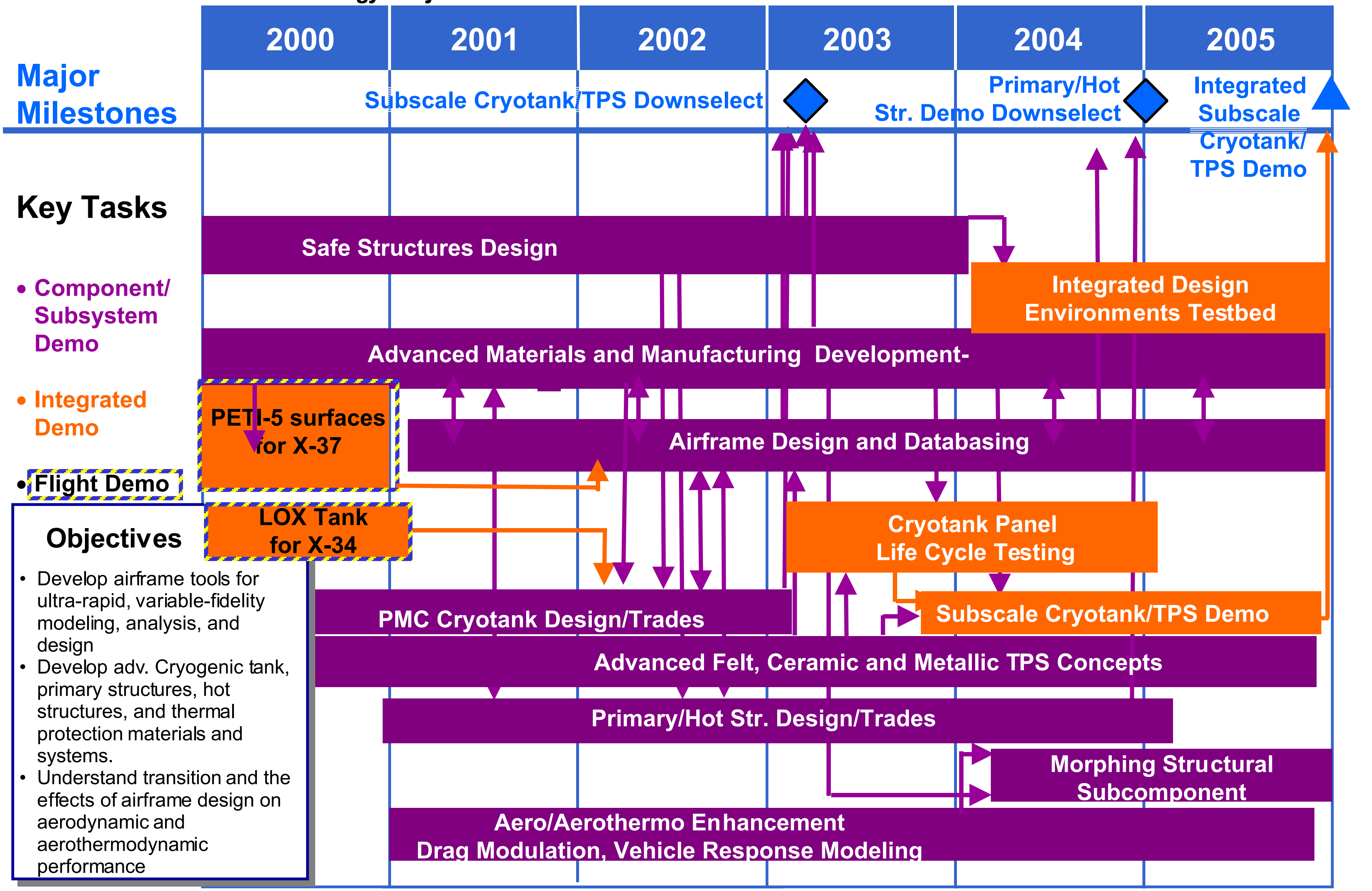
Thermal Protection Systems
(ARC Lead)



Aero/Aerothermo Enhancement
(LaRC Lead)
No FY00 Funding

Airframe Technology Project Roadmap

Airframe Technology Project — 2000 PMC



Objectives

- Develop airframe tools for ultra-rapid, variable-fidelity modeling, analysis, and design
- Develop adv. Cryogenic tank, primary structures, hot structures, and thermal protection materials and systems.
- Understand transition and the effects of airframe design on aerodynamic and aerothermodynamic performance

5536.4

Bantam Technologies *are the First Steps* of the Critical 3rd Generation Spaceliner Blueprint

Advanced Operations
- Automated Umbilicals
- Autonomous Flight Safety System
- Mag Lev Launch Assist

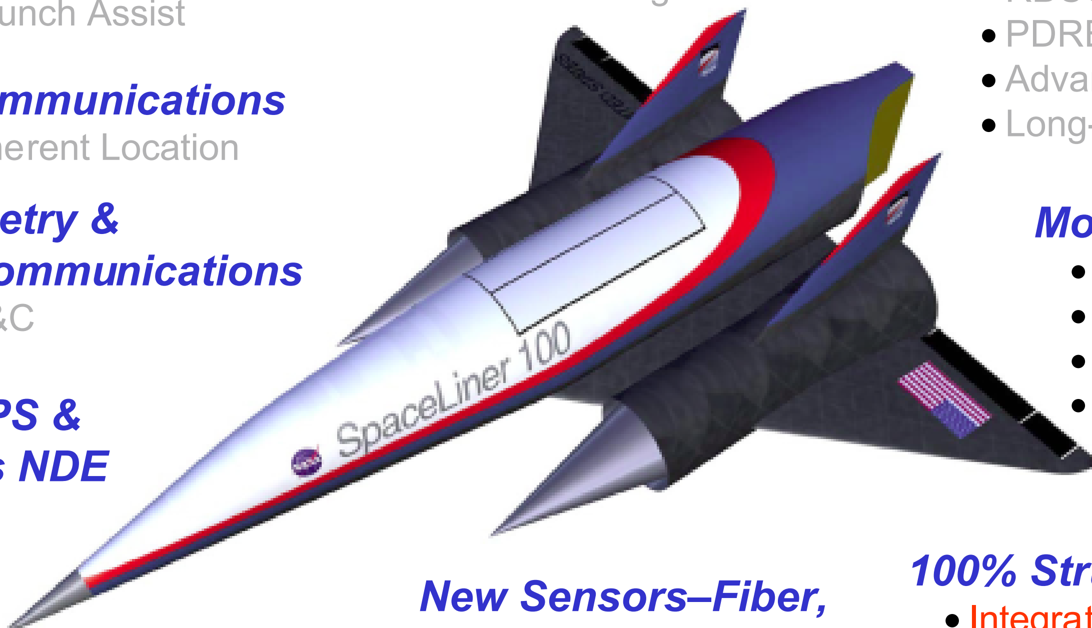
Wireless Communications
- Passive Coherent Location

Smart Telemetry & Advanced Communications
- Robust GN&C

Intelligent TPS & Autonomous NDE
- Smart TPS

Distributed Active Control & Self Healing Airframes & Surfaces
- Smart Sheet Sensors

Integrated Propulsion Health Management
- IVHM Diagnostic S/W



New Sensors–Fiber, SiC, MEMS, Leak, etc.
- High Density Structural Sensors
- Smart, Multi-function Sensor Development

Advanced Propulsion Systems
- RBCC
- PDRE
- Advanced Propellants
- Long-life Rocket

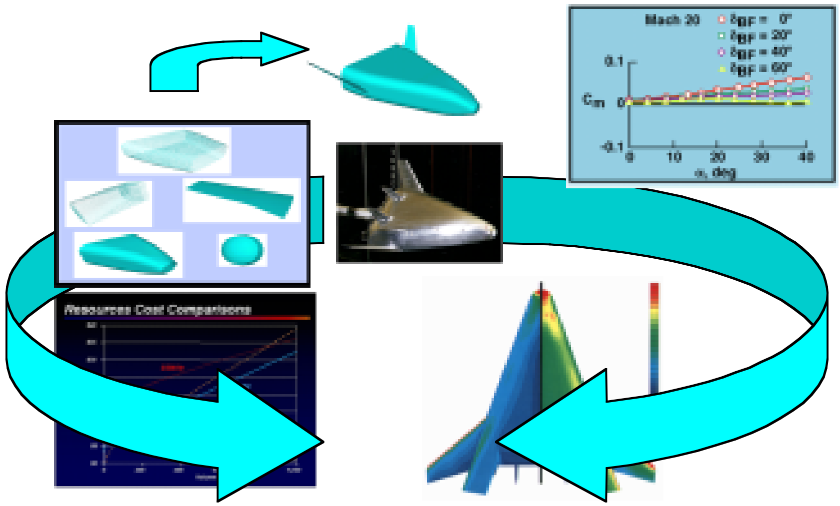
Modular Distributed Avionics
- Reconfigurable Avionics
- Super Capacitors
- Rechargeable Lithium Batteries
- High Voltage Switch Gear

100% Structural & TPS Coverage
- Integrated MPS Cryotank
- Ultra High Temp PMC's
- Advanced Adhesives & Sealants
- Non-Autoclave Fabrication of PMC's
- CMC Life Prediction
- Ultra High Temp Leading Edges
- Low-cost, Erosion Resistant TPS
- Advanced Stitched Composites
- Composite LOX Tanks

Legend:
- *Spaceliner Critical Technologies*
- **Bantam Technologies moved to Airframe Technology Proj.**
- **Other Bantam Technologies**

STD5481

Integrated Airframe Design



Long-term major goals:

- Integrated advanced design and analysis technologies leading to substantial reductions in design cycle time
- Ultra-rapid variable-fidelity modeling, accurate analysis, and redesign of structural concepts
- Verified fail-safe airframe analysis and design methodologies

Integrated Airframe Design

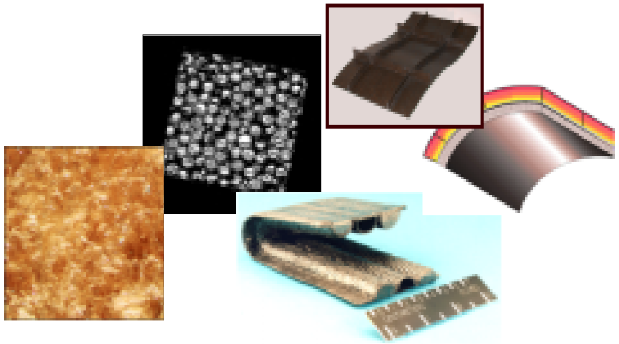
♦ Description of Technology

- Polymer matrix composite damage tolerance
- Safe Structures Analysis and Design Technologies

♦ Participants:

MSFC, LaRC, AFRL, ORNL, Boeing, Stanford

Integrated Thermal Structures and Materials

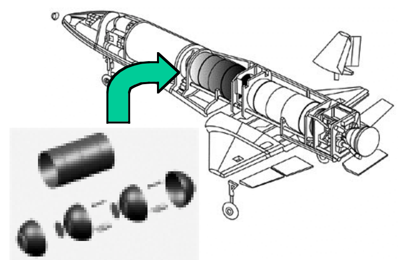


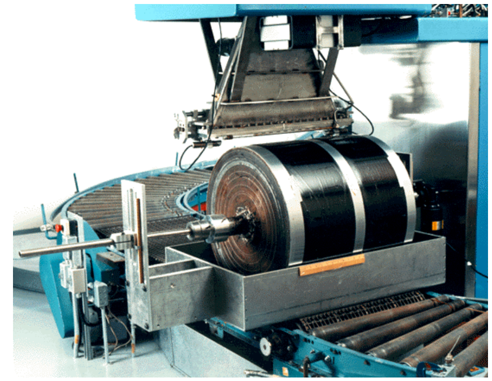
Long-term major goals:

- Development of new metallic and polyimide foams, metal alloys, ceramic matrix composites, metallic matrix composites, and hybrid metallic and polymeric composites.
- Near net and free form manufacturing of large, unitized metallic structure, non-autoclave manufacturing processes and low cost, automated assembly technology
- Development of advanced and smart/adaptive, hot and cooled airframe structures
- Development of advanced cryotanks of organic composite and metallic alloys and metal matrix composites

♦ Description of Technology

- **Advanced Adhesives and Sealants**
- **Non-autoclave Fabrication of Polymer Matrix Composites**
- **Carbon-Carbon Control Surface Modifications**
- **Ultrasonic Spectroscopy for Composite Adhesive Bond Strength Determination**
- **Stitched, High Temperature Polymer Composite Cryotank Technology**
- **Integrated MPS Cryotank System**
- **Advanced Composite LOX Tank for X-34**
- **Graphite/PETI-5 Composite Aero Surfaces for X-37**

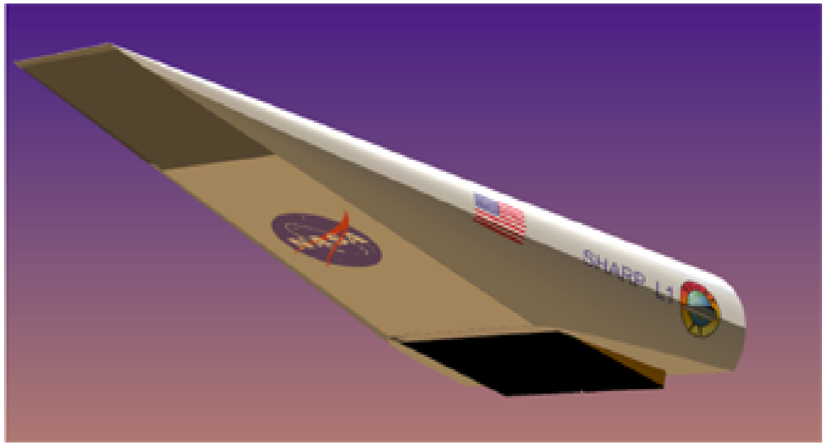




♦ Participants:

ARC, DFRC, GRC, LaRC, MSFC Sverdrup, ASRI, Thiokol, Southern Research Institute, Alliant Tech Systems, Boeing,Lockheed-Martin, Michigan State University

Thermal Protection Systems



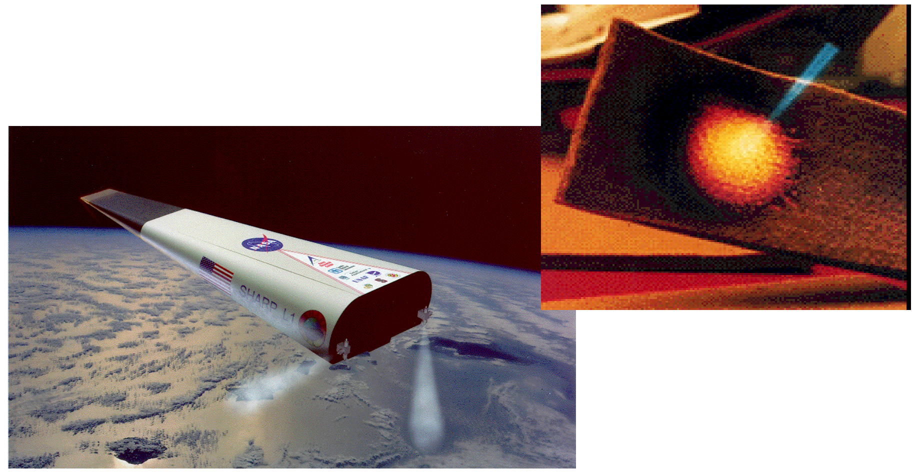
Long-term major goals:

- Necessary ground development and characterization of ultra-high temperature ceramics which will enable sharp body hypersonic vehicles
- Development and demonstration of highly reusable TPS with extended life cycle capabilities, including "most" weather flight capability and fail-safe performance
- Assessment, simulation, and prediction of TPS degradation and failures

Thermal Protection Systems

♦ Description of Technology

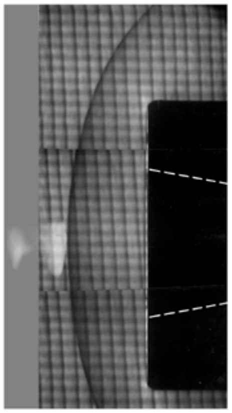
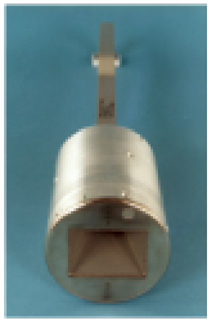
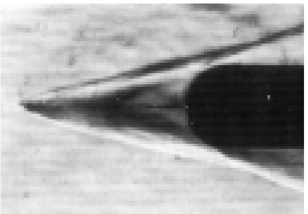
- High Temperature Felt TPS
- Quick Process, Low Cost Erosion Resistant TPS
- Advanced High Temperature Structural Seals
- Subsurface Microsensors for Assisted Recertification of TPS
- Ultra-High Temperature Ceramics and SHARP L-1 Ground Development



♦ Participants:

ARC, GRC,
Sandia, Boeing, HC Chem,
TexTech Industries, Penn. State University

Aero/Aerothermo Enhancement

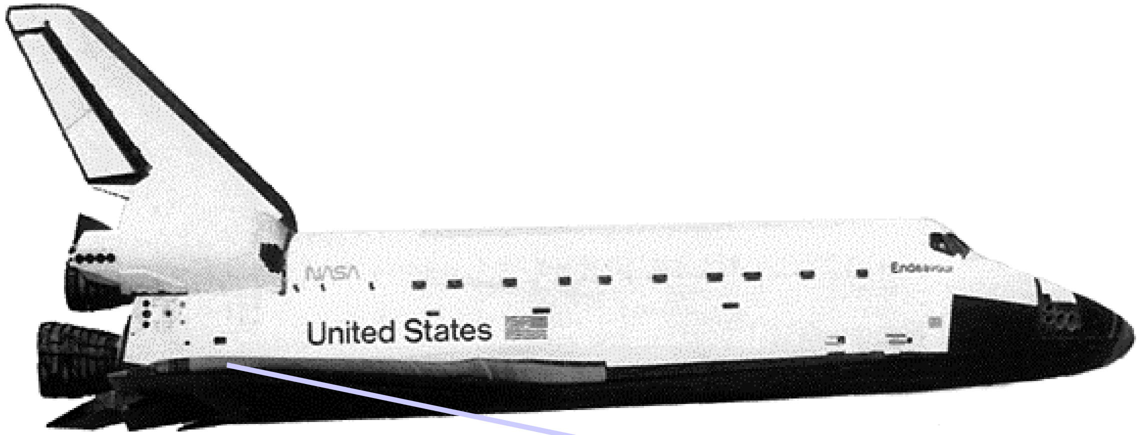
Long-term major goals:

- Design methods of complementary experimental and computational tools for rapid assessment of optimization of aerodynamic and aeroheating characteristics for proposed vehicle concepts in initial design
- Reduce margins/uncertainties associated with complex flow phenomena
- Aerodynamic optimization resulting from advanced flow physics techniques and devices.

Major Accomplishments FY98/99/00

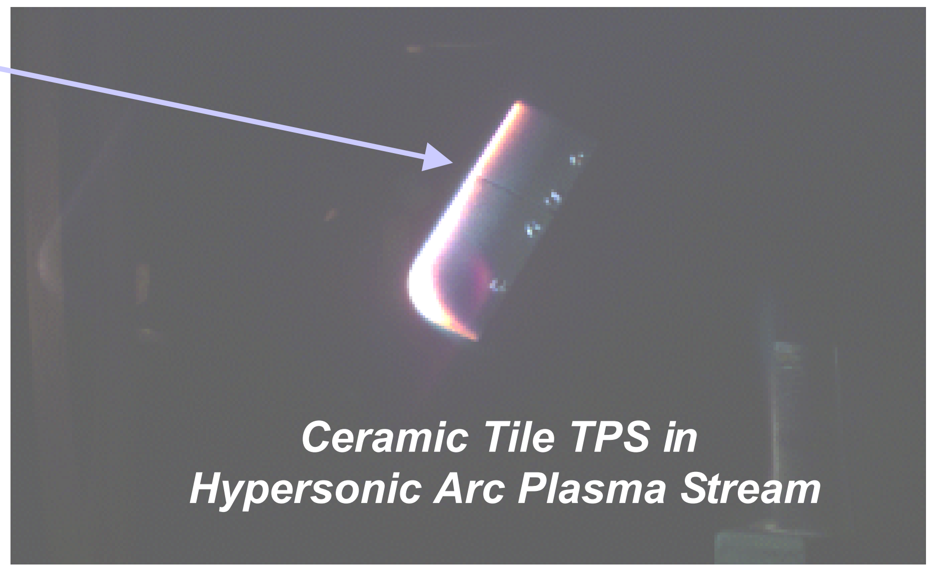
Date		Progress	
Planned	**Actual**	**Accomplishment**	**Significance**
4QFY99	***4QFY99***	***Demonstrate higher temperature quicker processed ceramic tile***	***Arc jet testing completed on candidate tile at 3000°F for 2 and 4 mins. Cheaper to fabricate, easier to use, and maintain leading edge materials***
4QFY99	*4QFY99*	*Develop non-autoclave processable adhesives*	*Excellent adhesive bonds using only vacuum bag pressure. Eliminating the autoclave requirement while maintaining performance leading to reduced cost.*
4QFY99	*4QFY99*	*Complete preliminary thermal analysis for control surface seal technology*	*Established seal requirements. Enabling technology for lower profile TPS , more aggressive structural components leading to reduced weight*
1QFY00	*1QFY00*	*Complete preliminary design of Integrated MPS Cryotank*	*System and test requirements, conceptual design, component test definition, and test structural design complete. Elimination of inner tank leading to significant weight and cost reduction*
2QFY00	*1QFY00*	*Complete Preliminary Design LOX tank for X-34*	*Preliminary design established. Begun fabrication of qualification unit. Flight demonstration of technology*

Higher Temperature Capability Tile Leading Edge



- ***Current ceramic TPS limited to 2700^{o}F***

- ***Candidate ceramic TPS tested at 3000^{o}F for 2-4 mins***



Ceramic Tile TPS in Hypersonic Arc Plasma Stream

Major Accomplishments FY98/99/00

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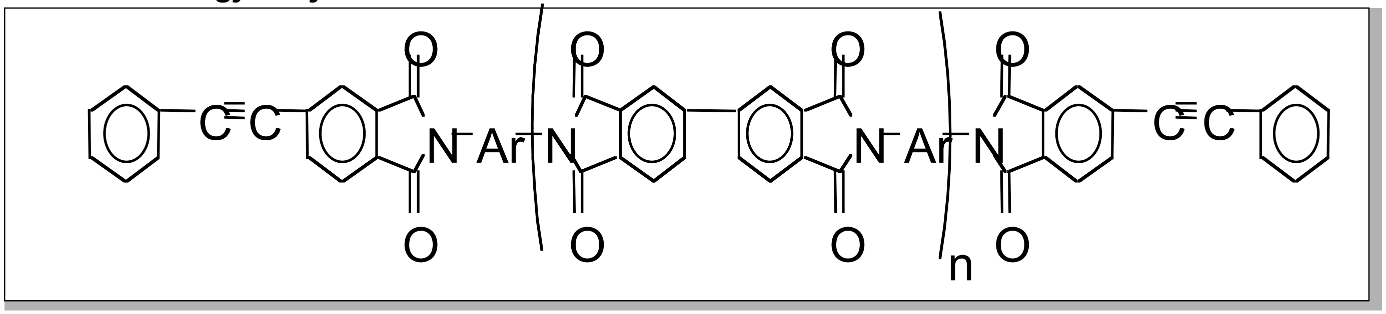
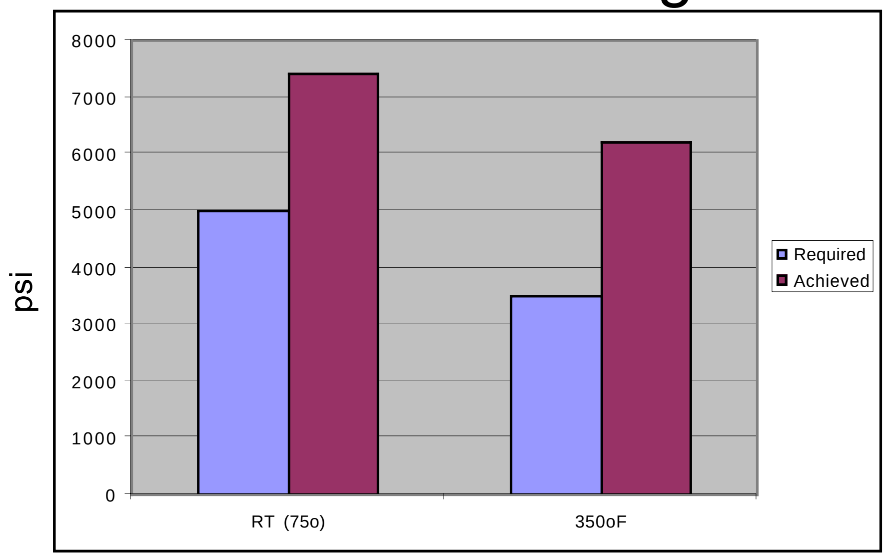
Advanced Adhesives and Sealants

LaRC PETI-8, Advanced Adhesive



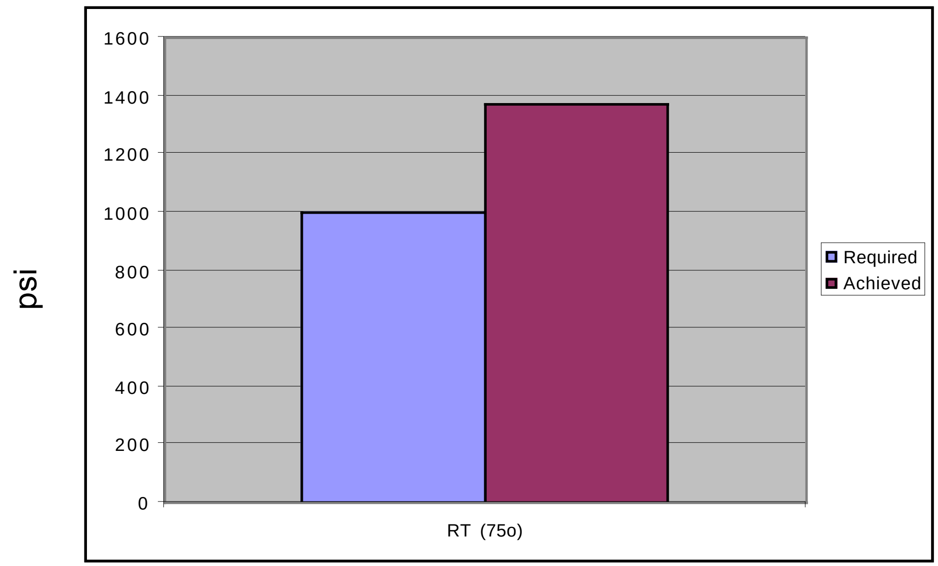
Bonding Conditions: Vacuum Bag Only Pressure, 600°F, 8 hour hold, 5V CAA surface treatment

Titanium to Titanium Tensile Shear Strengths



Flatwise Tensile Strength

(Composite Skins over Titanium core)



Major Accomplishments FY98/99/00

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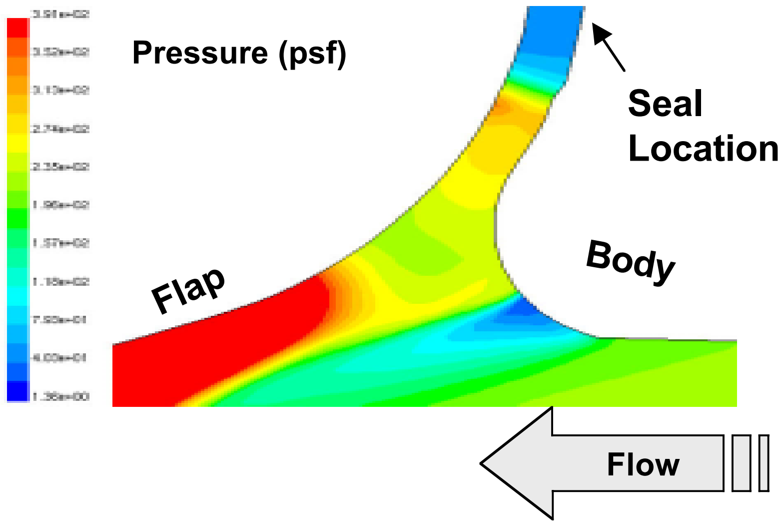
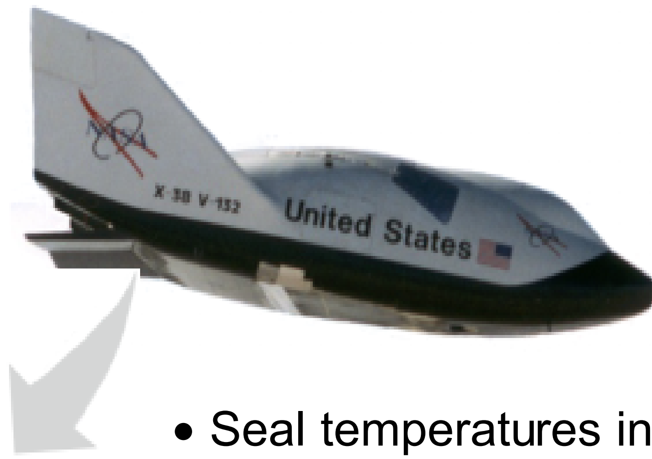
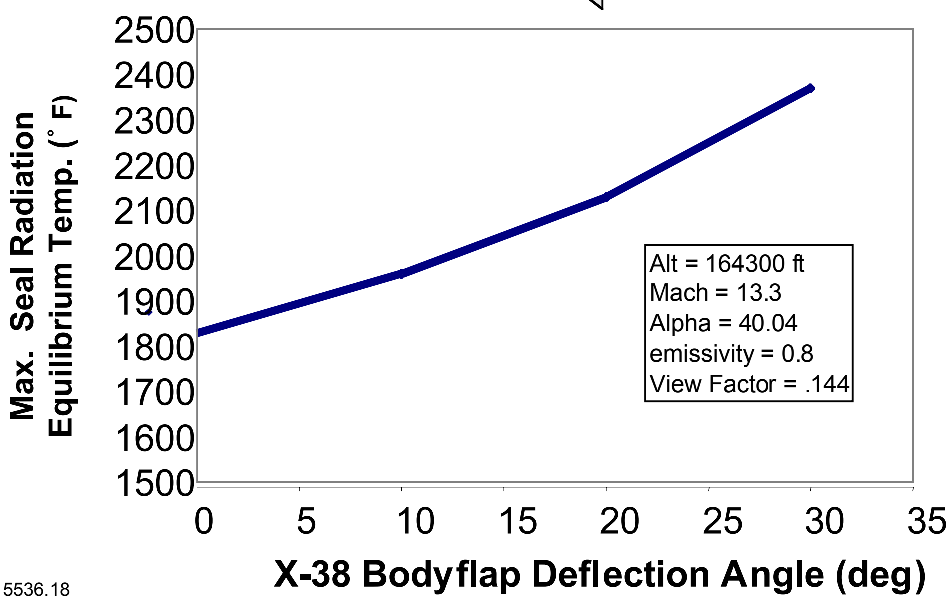
Control Surface Seal Technology Development
Preliminary Thermal Analyses Completed

Airframe Technology Project **2000 PMC**

Static Pressure Distribution In Body Flap Gap & Seal Area







- Seal temperatures increase as body flap deflection angle increases
- Maximum seal surface temperatures are expected to be in the range of 2200-2400°F for a 20-30 degree flap deflection.
- Seal temperatures expected to be higher than Shuttle experience requiring advanced seal technology development.

Major Accomplishments FY98/99/00

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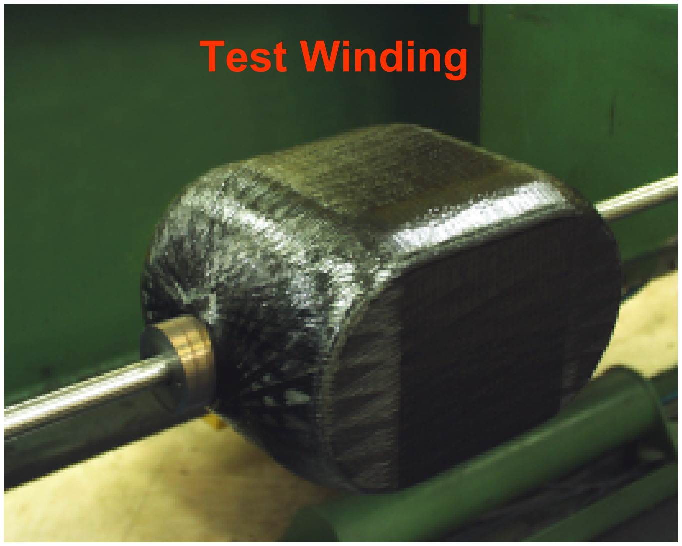
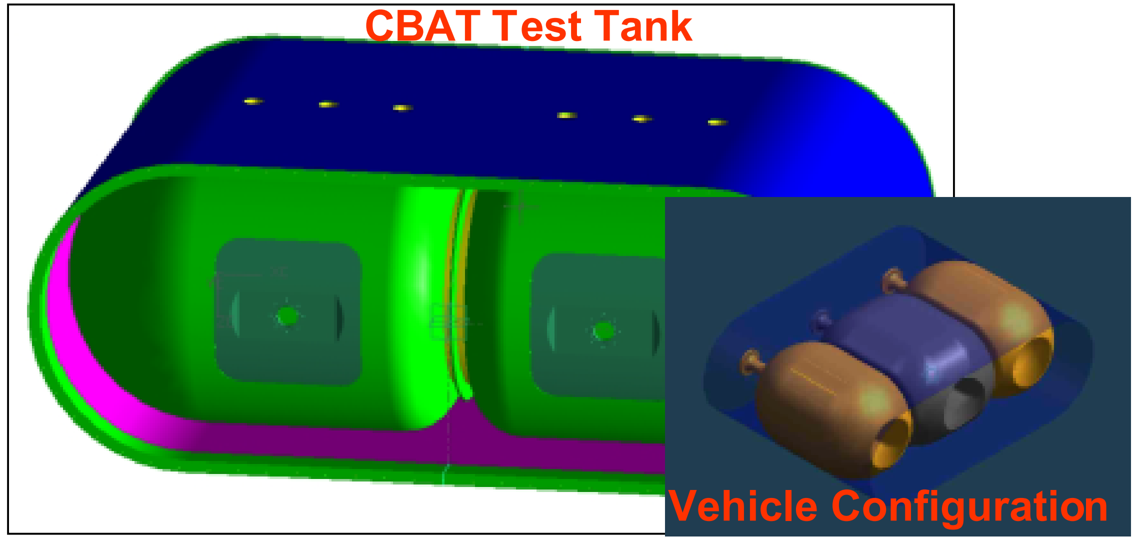
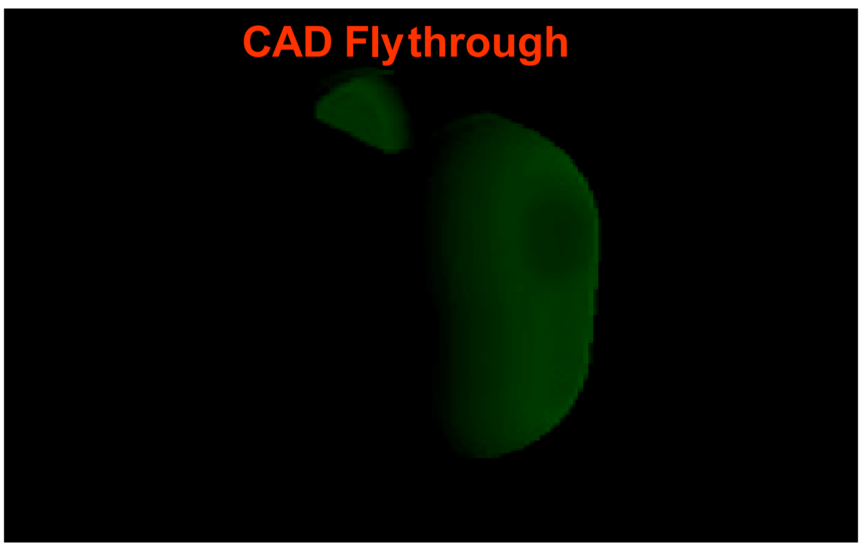
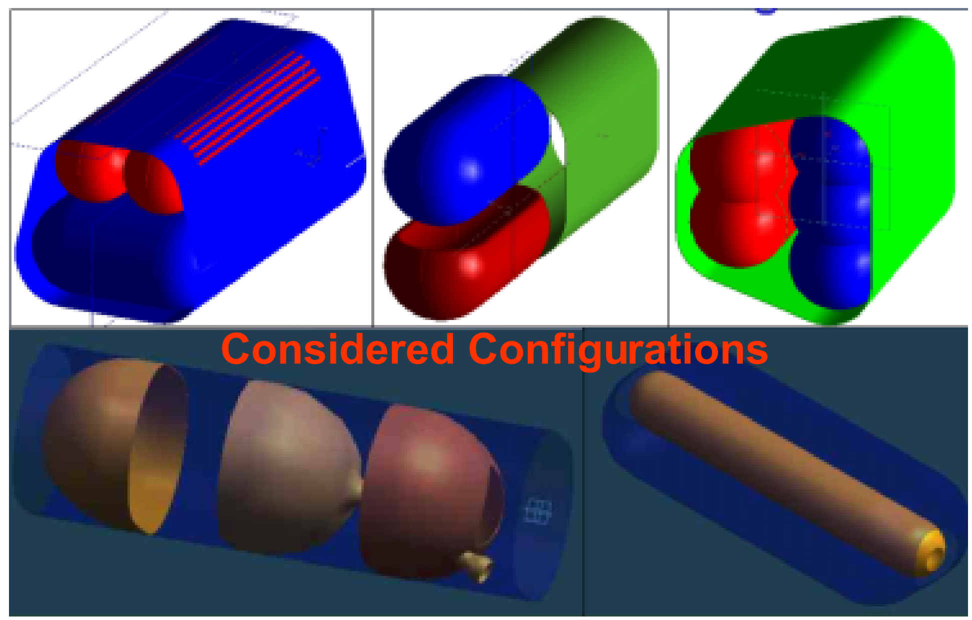
Integrated MPS Cryotank System









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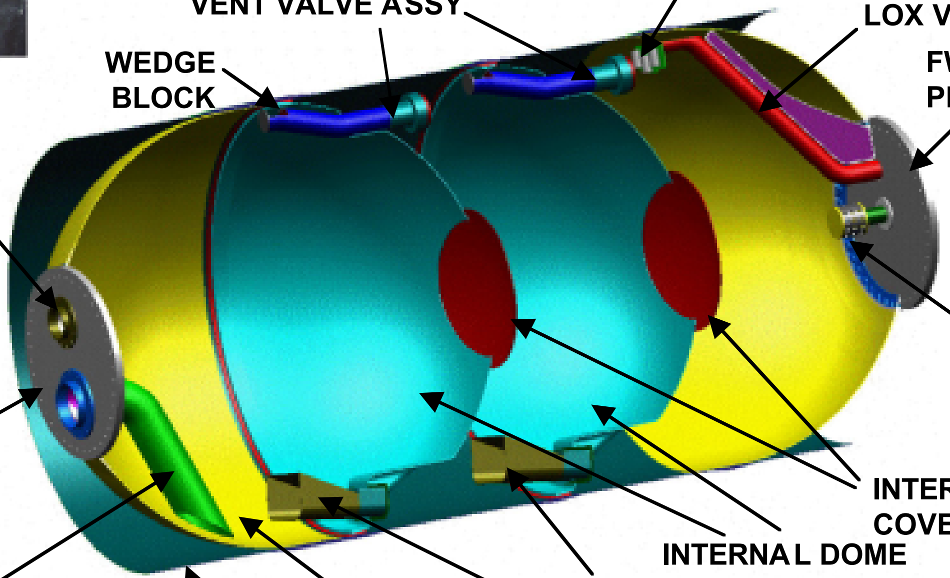
Composite LOX Tank for X-34



Milestone Status

- **Milestone: Evaluate damage progression analysis methods to assess damage tolerance of composite structures**

  G

  - Planned Completion Date: 9/01
  - Output: Damage tolerance material database, validated damage prediction tools and damage tolerance criteria
  - Outcome: Identifying key drivers to reduced cost by guiding manufacturing, handling and operating procedures
  - Status: On-schedule. Completed intermediate milestones of accessing existing repair methods. In general, most skin-stringer structural concepts repaired with bonded patch concepts. Sandwich concepts involved sandwich repair concepts.

- **Milestone: Develop composite structures damage tolerance criteria that relate structural weight and reliability**

  G

  - Planned Completion Date: 9/01
  - Output: Verified fail-safe and reliability based structural analysis and design technologies.
  - Outcome: Fail-safe design of reliable lightweight structures
  - Status: On-schedule. Initiated FY00.

Milestone Status

- **Milestone: Optimized performance of best adhesive**

  G

  - Planned Completion Date: 12/00
  - Output: Non-autoclave processable adhesive
  - Outcome: Improved manufacturing process by relieving size and shape constraints due to autoclave processing while maintaining performance.
  - Status: On-schedule. Developed novel high temperature adhesive that can be processed using vacuum bag pressure only.

- **Milestone: Design and fabricate subcomponent with e-beam cured high-temperature polymer matrix composite**

  G

  - Planned Completion Date: 3/01
  - Output: Validated non-autoclave process for fabrication of large PMC structure
  - Outcome: Fabrication of very large composite structure without the use of expensive over-sized autoclaves
  - Status: On-schedule. Final assembly of tape placement device is underway. Fabrication of e-beam by Electron Solutions underway. Synthesis of candidate materials underway.

Milestone Status

- **Milestone: Complete testing of modified carbon-carbon control surface**

G

  - Planned Completion Date: 9/00
  - Output: Documentation of room and elevated temperature testing of modified torque tube control surface.
  - Outcome: Refractory composite hot-structures control surfaces have the potential to eliminate the TPS requirement for advanced reusable launch vehicles which could potentially reduce weight, and reduce operation and maintenance requirements.
  - Status: On-schedule. Design modifications complete. Fabrication in progress.

- **Milestone: Ultrasonic evaluation and mechanical property correlation**

G

  - Planned Completion Date: 12/00
  - Output: Measure relationship between ultrasonic spectroscopy and ultimate bond strength
  - Outcome: Quantitative information regarding the integrity of adhesive bonds enabling significant weight savings through the use of composite structures.
  - Status: Initiated FY00.

Milestone Status

- **Milestone: Subcomponent fabrication and evaluation of stitched, high temperature PMC for cryotank applications.**

  G

  - Planned Completion Date: 9/01
  - Output: New/modified polymer matrix formulations, design concepts, demonstration hardware, and subcomponent testing
  - Outcome: Improved durability via stitching. Weight reduction due to reduced TPS and insulation requirements through use of higher temperature resin system.
  - Status: Initiated FY00. Contract in negotiation.

- **Milestone: Preliminary Design Review of LOX tank for X-34**

  G

  - Planned Completion Date: 1/ 00
  - Output: Hold preliminary design review of composite LOX tank for X-34.
  - Outcome: The tank being fabricated in this activity will become the first composite liquid oxygen tank to be flight tested. The long-term impact of utilizing low cost lightweight composites in liquid oxygen tank applications will be to reduce the cost of access to space.
  - Completed 12/10/99

Milestone Status

- **Milestone: Flight test hardware complete for the graphite/PETI-5 composite aero surfaces for X-37.**

  G

  - Planned Completion Date: 12/00
  - Output: Tested composites technology for warm primary structure.
  - Outcome: Reduced TPS and insulation requirements leading to significant weight savings.
  - Status:On-schedule. Initiated in FY00

- **Milestone: Characterization of various felt Thermal Protection Systems (TPS)**

  G

  - Planned Completion Date: 9/ 00
  - Output: Measurement of thermal and mechanical properties, thermo-chemical stability assessment and durability screening in a vibro-acoustic environment of a variety of felt TPS concepts.
  - Outcome: High temperature felts contribute to lower initial and recurring costs for reusable launch vehicles while enhancing the vehicle's rapid turn-around capability
  - Status: On-schedule. Manufactured a family of felt material candidate prototypes for material characterization and arc jet testing.

Milestone Status

- **Milestone: Plan to further improve robust tile TPS**

  G

  - Planned Completion Date: 1/01
  - Output: A family of advanced TPS that are low cost and erosion resistant. Based on the results from Phase 2, a plan detailing next step improvements in robust tile TPS
  - Outcome: Reduced installation and operation costs by improving TPS durability and reducing manufacturing cost.
  - Status: On-schedule. Higher temperature capability and a quicker processed ceramic tile TPS have been produced.

- **Milestone: Advanced high temperature structural seals**

  G

  - Planned Completion Date: 9/00
  - Output: Demonstrated advanced control surface seals.
  - Outcome: Higher temperature seals permit lower profile TPS, more aggressive structural components saving weight/enhancing performance/saving payload-to-orbit costs.
  - Status: On-schedule. Identified critical control surface seal design requirements.

Milestone Status

- **Milestone: Downselect sensors for flight testing on Shuttle on X-34 in FY02**

  G

  - Planned Completion Date: 10/01
  - Output: Small wireless microsensors and remote sensing/scanning technology for rapid TPS recertification.
  - Outcome: Greater than order-of-magnitude reduction in TPS operations costs compared to current Shuttle procedures.
  - Status: On-schedule. Delivered and successfully tested a thermal overlimit wireless sensor. Demonstration of anticollision hardware/software.

- **Milestone: Complete preliminary design of SHARP L-1**

  G

  - Planned Completion Date: 12/01
  - Output: Hold preliminary design review of SHARP L-1
  - Outcome: SHARP L-1 will demonstrate a variety of sharp body technologies which will allow an entirely new generation of aero-space vehicle designs that have substantially improved affordability and capabilities for space access
  - Status: On-schedule. Work Initiated in FY00

More Capable Ceramic Tile TPS Demonstrated

POC: Dr. Daniel Leiser
September 1999

Relevant Milestone: Task 2 - Quick Processed Erosion Resistant TPS, Higher temperature capability (3,000°F for 4 minutes) and a quicker processed ceramic tile TPS produced, 9/29/99

Shown: A graphic of an entry vehicle with a higher temperature capability tile TPS leading edge being tested in a hypersonic arc plasma stream. Tile will be cheaper, safer and easier to repair than current leading edge materials such as Advanced Carbon Carbon (ACC).

Accomplishment / Relation to Milestone and ETO: Arc jet testing was completed on candidate ceramic tile TPS at 3,000°F for 2 and 4 minutes (Tile TPS currently limited to 2700°F); arc jet testing was completed on candidate QUICTUFI tiles at 2800°F for 5 minutes. These tiles require less labor to produce than current tiles, and their higher multi-use temperature allows them to substitute for more expensive, difficult to replace, and flaw sensitive materials (e.g.. carbon/carbon) on the leading edges. This improvement reduces the overall cost of TPS, taking a substantial step towards the ETO goal of $1.5M/flight.

Future Plans: The next step is to further extend the temperature capability of the materials under development and continue efforts to reduce the labor required to produce these materials.

ETO: Reduce access-to-space costs and increase re-usable space vehicle system reliability

PETI-8, A Non-autoclave Processable Adhesive

POC: Dr. Brian J. Jensen, LaRC
December, 1999

Relevant Milestone: Develop non-autoclave processable adhesives.

Shown: LaRC PETI-8 is a phenylethynyl terminated polyimide adhesive which has low melt viscosity and excellent melt stability at temperatures below 572°F, allowing the production of excellent adhesive bonds under vacuum bag pressure, without the need for external pressure normally supplied by an autoclave. Heating at 600°F for 8 hours provides excellent titanium to titanium tensile shear strengths from 75°F to at least 350°F and excellent flatwise tensile strengths at 75°F.

Accomplishment / Relation to Milestone and ETO: A novel high temperature adhesive has been developed which can be processed using vacuum bag pressure only, not requiring an autoclave for external pressure.

Future Plans: Continue work on adhesives which do not require an autoclave for processing. Concentrate on vacuum bag / oven processing, hot melt adhesives and the use of e-beam radiation to cure advanced adhesives. Optimize the properties of LaRC PETI-8 by studying various formulations of the adhesive tape and various cure conditions.

ETO: Reduce access-to-space costs and increase re-usable space vehicle system reliability

BANTAM TPS-20, Advanced High Temperature Structural Seal Development
Task Lead: Dr. B. Steinetz / NASA GRC
Status as of: December, 1999

Relevant Milestone: Demonstrate control surface seals for next generation re-usable space vehicles under re-entry heating conditions (September, 2001)

Shown: Thermal analyses results showing control surface gap pressure and anticipated seal temperature versus representative body flap angles. Reference Case: X-38 re-entry mission.

Accomplishment / Relation to Milestone and ETG: Thermal analyses of control surface and seal under representative re-entry heating conditions (ref. X-38 re-entry mission) have shown control surface seal temperatures will be up to 2400˚ F, depending on body-flap deflection angle. These temperatures are approximately 1000˚F hotter than Shuttle metal seals and 400˚F hotter than Shuttle ceramic seals. Smaller next-generation re-usable vehicles have less space for seals than Shuttle, requiring placement in hotter regions.

Currently advanced seal concept development and verification tests are underway to demonstrate seals capable of these more severe conditions.

Future Plans:
Develop advanced seal concepts showing promise of meeting requirements: perform durability, permeability and arc-jet heating tests to evaluate competing concepts; validate thermal analysis predictions, develop seal design guidelines, and demonstrate a suitable seal concept.

ETG: Reduce access-to-space costs and increase re-usable space vehicle system reliability.

CBAT: Composite, Conformal, Cryogenic, Common Bulkhead, Aerogel-insulated Tank (STR-11, Integrated MPS Cryotank System)

POC: Jeff Finckenor/MSFC

Status as of: December, 1999

Relevant Milestone: Completion of Preliminary Design for the Integrated MPS Cryotank (3Q/FY99). System and test requirements, conceptual design, component test definition, and test structure design was completed. In addition, key testing such as process testing for winding conformal shapes, mechanical testing and thermal conductivity testing of the aerogel sleeves is underway, and long lead material and tooling have been ordered.

Shown: 1) Photo of 1/5 scale test winding of conformal shape; 2) Images of Integrated tank test assembly and a projected vehicle configuration; 3) Images of considered conceptual designs; 4) CAD MPEG movie flythrough of major components

Accomplishment / Relation to Milestone and ETO: The 3rd Pillar of the Aerospace Technology Enterprise is Access to Space, including demonstrating next generation technology to significantly reduce launch costs. The CBA Tank integrates a number of technologies such as common bulkheads using Aerogel insulation into a system demonstration with promise for significant cost and weight reductions. Composites and a Common Bulkhead promise enormous cost and part count reductions. Eliminating an intertank is a major weight reduction reducing the overall size and cost of a vehicle. Conformality allows efficient packing of tanks within aerodynamic shapes reducing support structure and its associated cost and weight. Due to the integrated nature of the CBA Tank, integrated design and analysis is essential. Analytical models are using CAD models for geometry, and the thermal and stress models will be combined to provide as high fidelity analysis as possible. Design tools are also developing flat patterns which will be electronically transferred to the shop floor.

Future Plans: The next step is a full scale winding which will be used as a pathfinder for manufacturing processes to be used on the test unit, as well as to provide test coupons to validate the analytical models. This will be followed with manufacture of a development unit, then the test unit, and finally the structural/thermal testing of the system.

ETO: Reduce access-to-space costs and increase
re-usable space vehicle system reliability

Composite LOX Tank for X-34

POC: Michael A. Phipps, MSFC

December 10, 1999

Relevant Milestone: Completed Preliminary Design Review (PDR) of Composite Liquid Oxygen (LOX) Tank for X-34 Program/Project Plan milestone 2nd Qrt. FY00.

Shown: The figure shows both the liquid oxygen tank design and two photographs of the barrel of actual qualification unit. The barrel is inserted into an autoclave MSFC for curing.

Accomplishment / Relation to Milestone and ETO: Completed PDR for composite LOX Tank. The tank is designed to reduce main propulsion weight in excess of 10% leading to reduced cost of access to space. The graphite polymer matrix tank is approximately 9' X 4.5' in size with one internal dome planned for the qualification unit and two internal domes planned for the flight unit. The domes are required to minimize sloshing and maintain center of gravity. Lockheed Martin and NASA are developing the tank for flight on the X-34 vehicle being developed by Orbital Sciences Corporation under contract to MSFC.

Future Plans: Complete fabrication, curing, and ground testing of qualification tank and build the flight unit for use on X-34 A-3 vehicle..

ETO: Reduce access-to-space costs and increase re-usable space vehicle system reliability

Schedule

	2000				2001			
	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4

Integrated Airframe Design

Polymer Matrix Composite Damage Tolerance

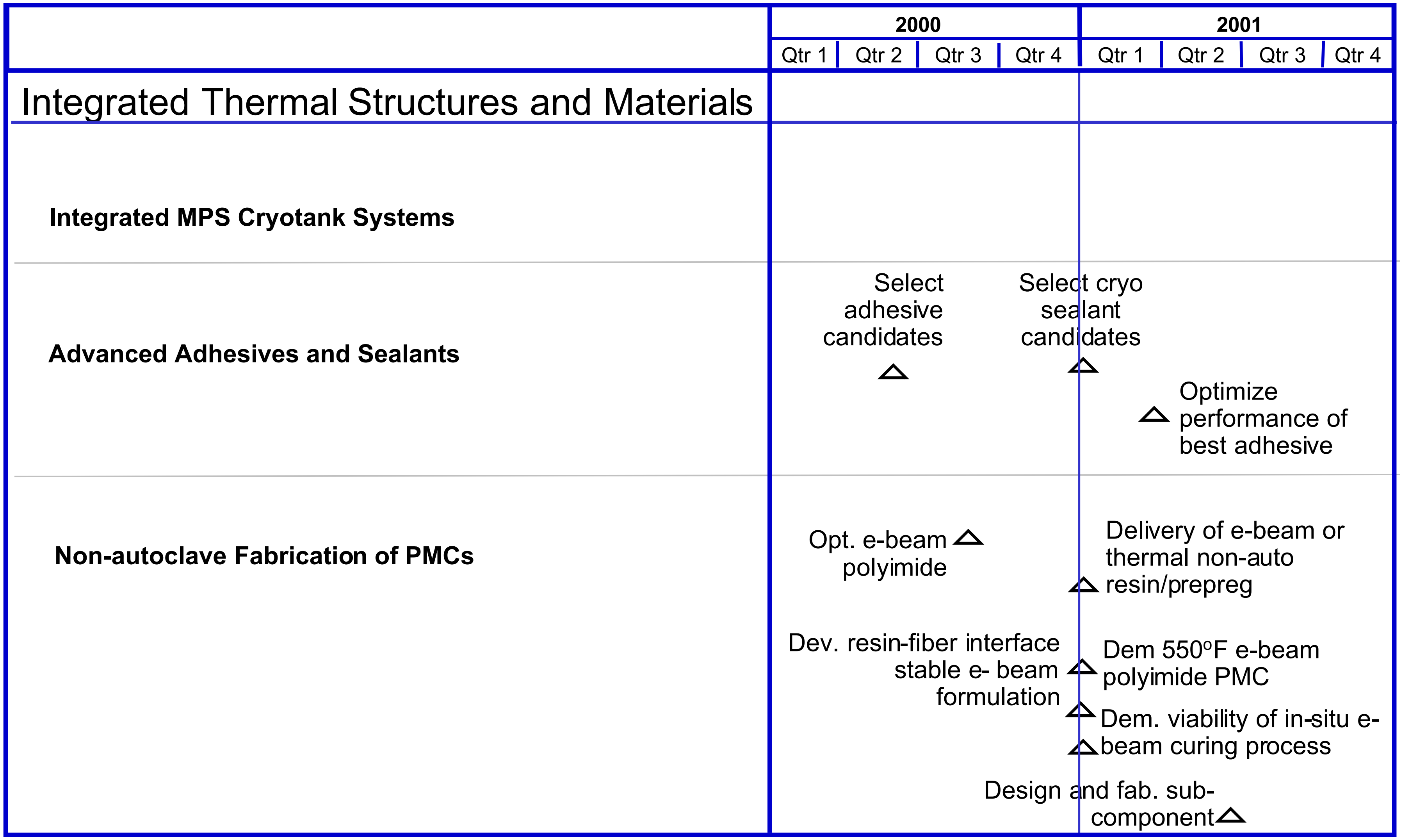
- Access existing repair methods
- Dev analysis methods for sizing repairs
- Dem repair for s/s construction
- Pressure leakage test
- Dem repair for sandwich construction
- Combined loads test w. known delam.
- Evaluate damage prog. Analysis methods

Safe Structures Analysis and Design Technologies

- Nonlinear progressive failure analysis and evaluate residual strength
- Damage tolerance criteria that relates structural weight and reliability

◆ - Program/Project Milestones

Schedule



◇ - Program/Project Milestones

Schedule

Integrated Thermal Structures and Materials	2000 (Qtr 1 – Qtr 4)	2001 (Qtr 1 – Qtr 4)
Carbon-Carbon Control Surface Modifications	Complete room and elevated temp tests	Complete final report; Complete testing of modified carbon-carbon surface
Ultrasonic Spectroscopy for Composite Adhesive Bond Strength Determination	Ultrasonic evaluations; Mech property evaluations	Ultrasonic/mech. correlations
Stitched, High-Temperature Polymer Composite Cryotank Technology	Design concept selection	New/modified resin evaluation; Subcomp. Fab and evaluation
Advanced Composite LOX Tank for X-34	◆ Complete preliminary design	

◇ **- Program/Project Milestones**

Schedule

	2000 Qtr 1	2000 Qtr 2	2000 Qtr 3	2000 Qtr 4	2001 Qtr 1	2001 Qtr 2	2001 Qtr 3	2001 Qtr 4
Integrated Thermal Structures and Materials								
Graphite/PETI-5 Composite Aero Surfaces for X-37	Design complete		Ground test complete	Flight test hardware complete				
Thermal Protection Systems								
High Temperature Felt TPS		First mat'l char. arc jet test report		Prelim. design evaluation of art jet test report	Characterization of felt TPS concepts			
Quick Process, Low Cost Erosion Resistant TPS		Interim test report		Final report Phase II robust tile TPS	Plan for further improvements			Prototype HT tile leading edge arc plasma model

◇ - Program/Project Milestones

Schedule

	2000 (Qtr 1, Qtr 2, Qtr 3, Qtr 4)	2001 (Qtr 1, Qtr 2, Qtr 3, Qtr 4)
Thermal Protection Systems		
Advanced High Temperature Structural Seal	Complete fabrication/feasibility-screening of leading seal candidates	Demo tech under sim. re-entry environment
Subsurface Microsensors for Assisted Recertification of TPS	Downselect thermal overlimit sensors for flt testing on Shuttle and X-34 Complete design of IVHM system for waterproofing burnout depth	Deter. level of accept. Damage from MMOD Prototype TPS defect database Downselect impact sensors for flt. testing
Ultra-High Temperature Ceramics and SHARP L-1 Ground Development	Complete multi-use UHTC leading edge design	Complete preliminary design of SHARP L-1

◇ - Program/Project Milestones